



Overview of IFE Chamber and Target Technologies R&D in the U.S *

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Mission of IFE Technology Activities



Address and resolve the critical issues for high-rep-rate chamber concepts, target fabrication and injection for heavy ion and laser drivers through assessment studies, experiments and numerical simulations.



Scope of IFE Technology Activities

- **R&D planning (with driver and target physics colleagues)**
 - Development paths and facilities, e.g., IRE, ETF, Demo
- **Chamber Technologies**
 - High rep-rate operation, protection of structures
- **Chamber/driver interface**
 - Protection of final focus magnets and laser optics
- **Safety and environmental**
 - Assessments and improvements to create attractive power plants
- **Target fabrication and injection**
 - Low cost, high pulse rate systems for ion and laser drivers
- **System integration**
 - Fitting the pieces together including target designs and drivers



Near Term (5-year) Goals

- **Demonstrate feasibility of chamber clearing for thick-liquid-wall chambers.**
- **Develop dry-wall chamber concepts that are tolerant of uncertainties in response of materials to fusion pulse and radiation damage.**
- **Develop plausible designs for protecting final focusing elements for ion accelerator and laser drivers.**
- **Evaluate safety and environmental aspects of IFE power plants and modify designs such that plants can meet the no-public-evacuation safety criteria.**
- **Demonstrate credible pathways to low-cost target fabrication, accurate injection, and target survival through experiments and analyses.**



Principal FY99/00 Achievements

- **R&D Planning**
 - Developed an integrated plan for R&D in Chamber and Target Technology for IFE.
- **Chamber Technologies**
 - Improved quality of liquid jets in several university experiments and demonstrated oscillating jet operation needed for thick-liquid-wall concept.
 - Initiated work on disruption of jets with chemical detonations and on Flibe vaporization/condensation experiments.
 - Conducted shock tube experiments to validate chamber dynamics models.
- **Chamber / Driver Interface**
 - Installed laser test facility to test final optics and laser/chamber interface issues.
 - Conducted 3D neutronics analyses of final focus designs for both ion and laser drivers.
 - Updated mechanical design of liquid shielding using crossed jets in HYLIFE-II.

Principal Achievements (cont.)



- **Safety and Environmental**
 - Completed first safety analysis of HYLIFE-II using safety codes developed for MFE and modified for IFE.
- **Target Fabrication and Injection**
 - Prepared experimental plan and design requirements for an experimental target injection system.
 - Identified potential methods of manufacture for both direct and indirect drive targets.

**Example highlights are given
for each of the following**



- **R&D Planning**
- **Chamber Technologies**
- **Chamber/Driver Interface**
- **Safety and Environmental**
- **Target Fabrication and Injection**
- **Summary**

A draft R&D plan was written in 1999 with wide community participation



Phase I (4-5 years) R&D focuses on feasibility issues



- **Thick liquid wall chambers**
 - Convincing evidence from scaled experiments and modeling that protective liquid pocket can be formed and that chamber can clear between shots
- **Dry-wall chambers**
 - Design that is more tolerant of uncertainties in material lifetime and evidence supporting wall life > 1 year
- **Driver / chamber interface**
 - Final focus magnet designs consistent with neutron shielding and illumination geometry required by target design
 - Design concepts and convincing evidence (from experimental data and modeling) that laser final optics (e.g., grazing incident mirrors and hot fused silica) will survive > 1 year

Phase I R&D focuses on feasibility issues (cont.)



- **Safety and Environment**

- Power plant designs with < 1 rem dose at site boundary consistent with measured release fractions for key radioactive isotopes.

- **Target Technologies**

- Demonstrate that a credible pathway exists for low cost target fabrication and accurate injection without damage to targets

Phase-I technology research focuses on key issues and supports decision to proceed with Integrated Research Experiment(s) (IREs)

Outline



- R&D Planning
- **Chamber Technologies**
- Chamber/Driver Interface
- Safety and Environmental
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Phase-I hydraulics experiments can be performed in university-scale facilities

- **Example: UCB facility studies single jets and few jets (partial pockets).**
- **Transient flow into large vacuum vessel**

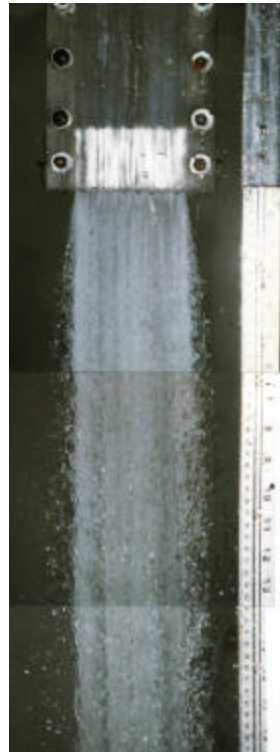
Water used to simulate Flibe
(allows Re, Fr and We number
matching at 1/2 to 1/4 geometric scale)



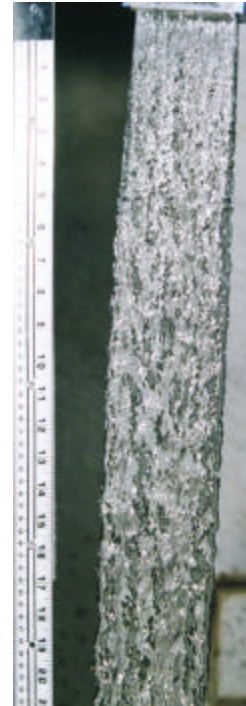
Single-jet experiments provide jet geometries for constructing integrated pockets



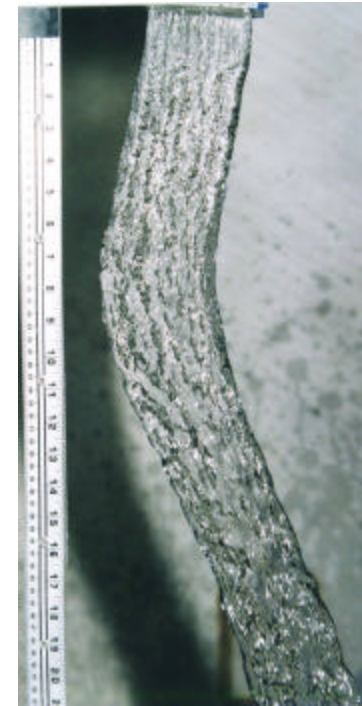
**Georgia Tech.
jet experiment**



**Bad:
Breaks up**



Stationary



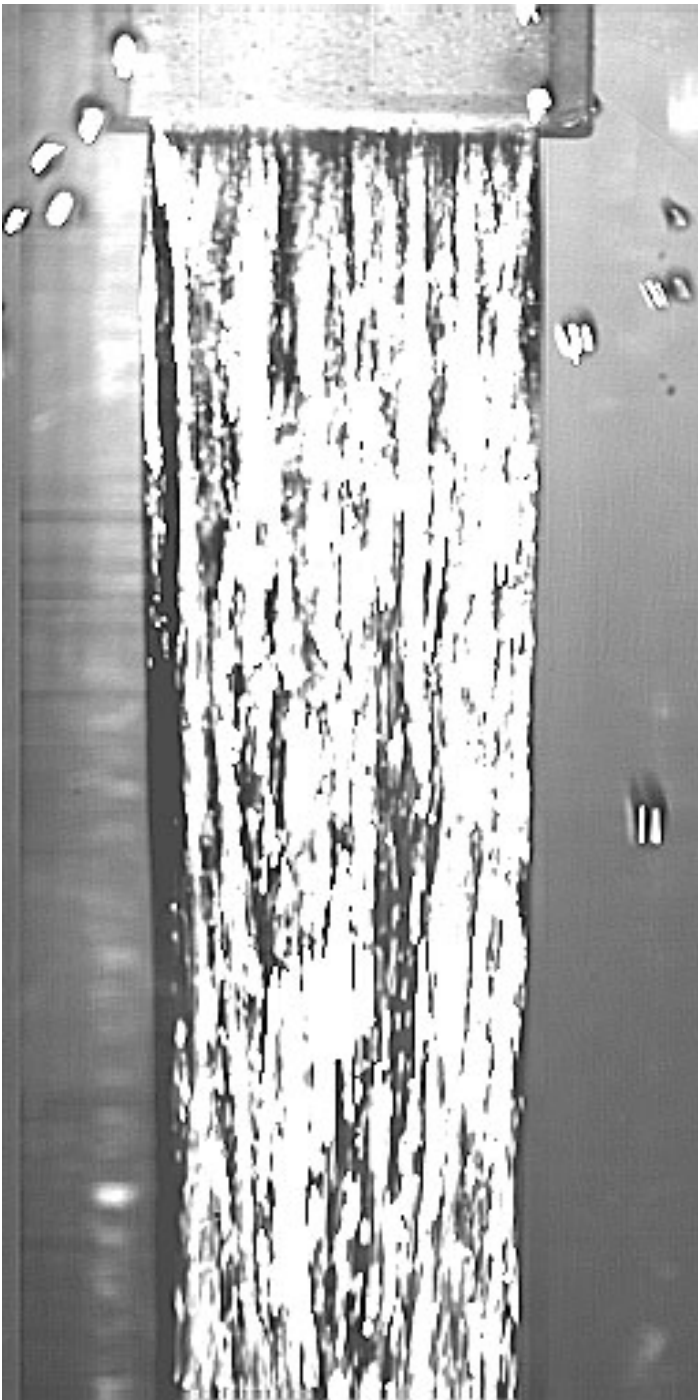
Oscillating

Better: No Droplets

**UCB Stationary Jets (1.6 cm x 8.0 cm,
view from flat side, $Re = 160,000$, $We = 29,000$)**

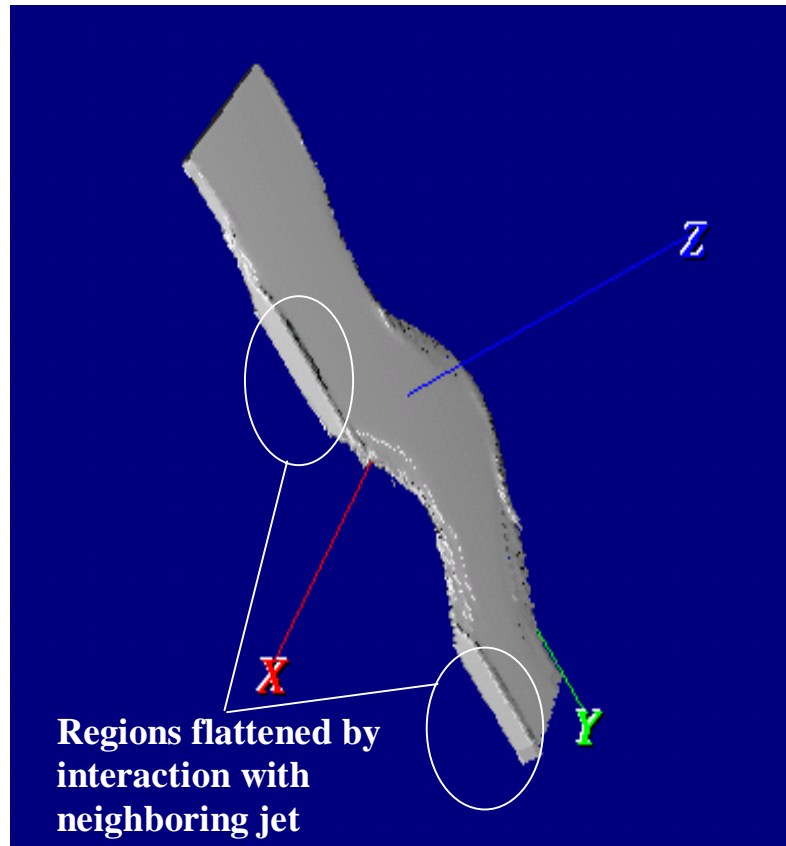
UC Berkeley

NAS2 view from flat side



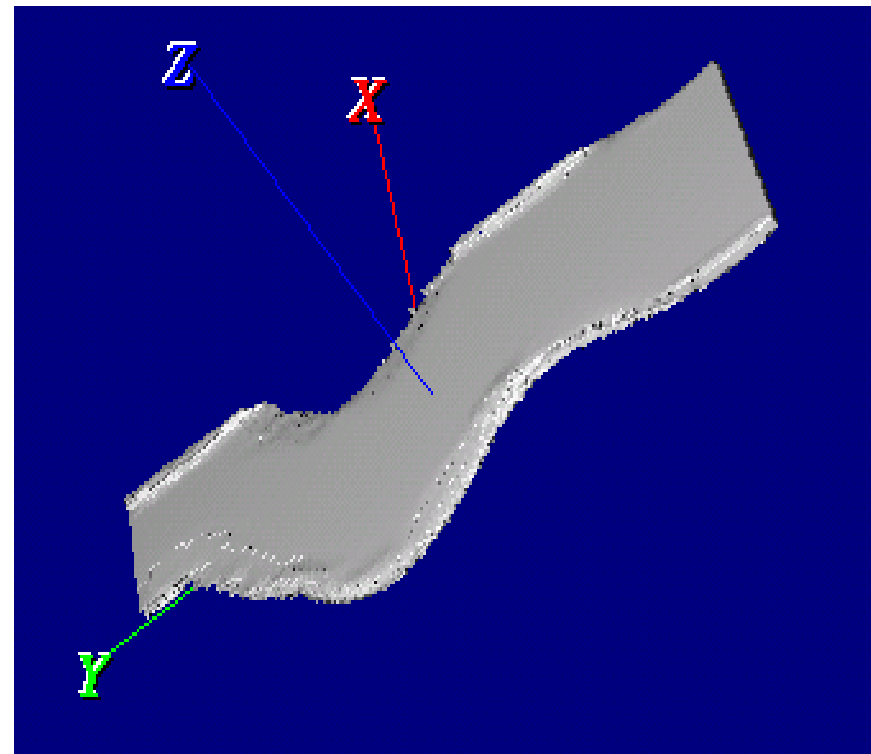
**Surface structures are 0.5 to 1.5 mm in width
 $V = 7$ m/s, Pictured Length 6 cm**

Free Surface Liquid Flow Modeling: *3D Simulation of Oscillating HYLIFE-II Jet*



Oscillation velocity parallel to free surface plane

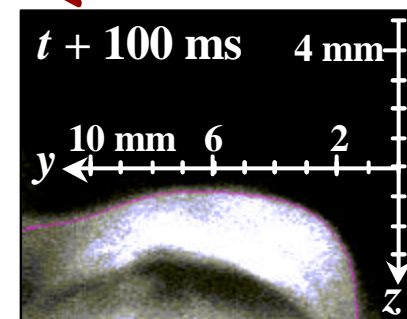
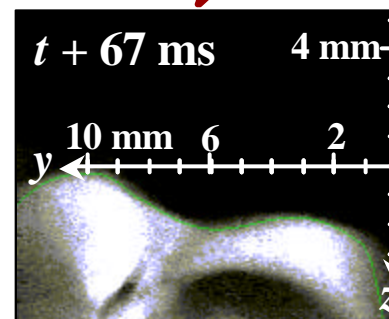
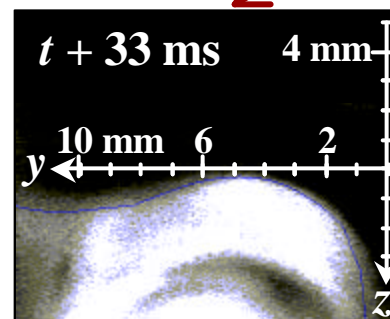
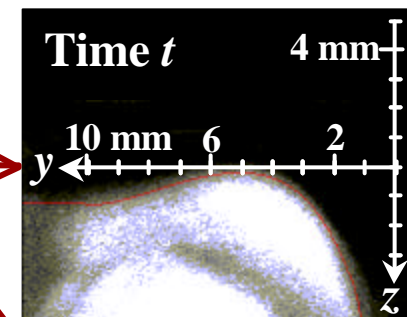
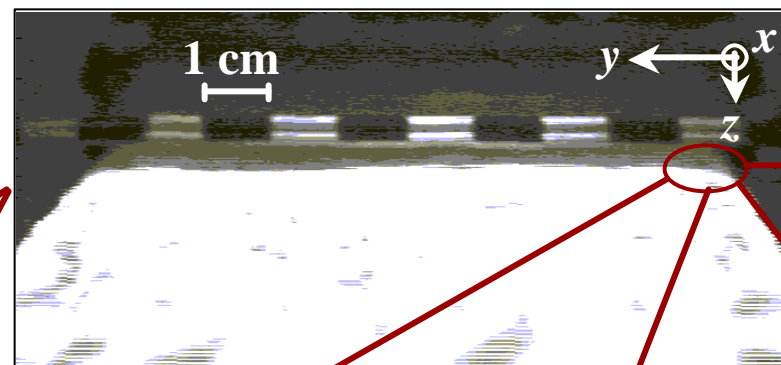
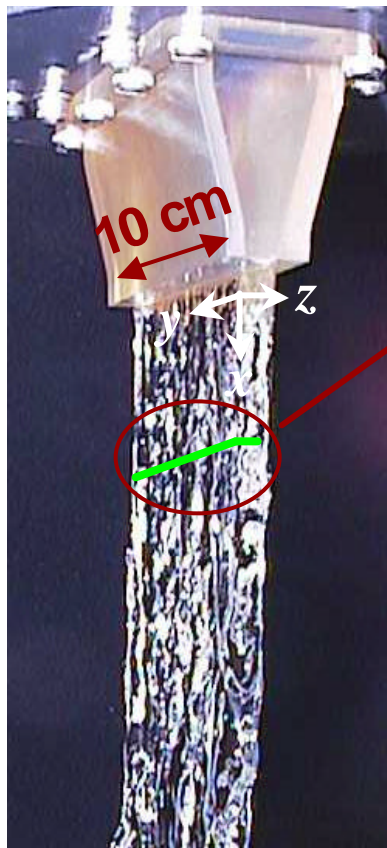
- Jet trajectory and pocket shape are consistent with HYLIFE design requirements
- Inter-jet spacing seals at pocket top and bottom due to interaction with "mirror" jets



Surface Ripple in Plane Jets

J. A. Collins, D. Sadowski, M. Yoda and S. I. Abdel-Khalik

Free surface visualization: Laser-Induced Fluorescence of jet fluid (water)



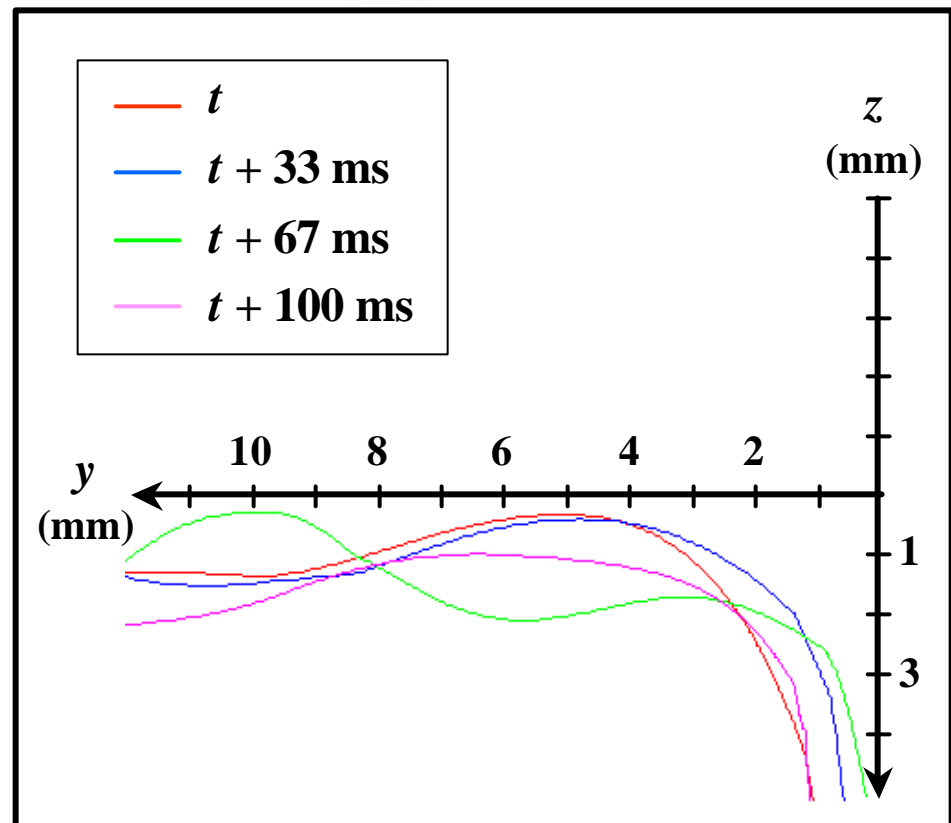
Surface Ripple in Plane Jets

Time evolution of free surface geometry

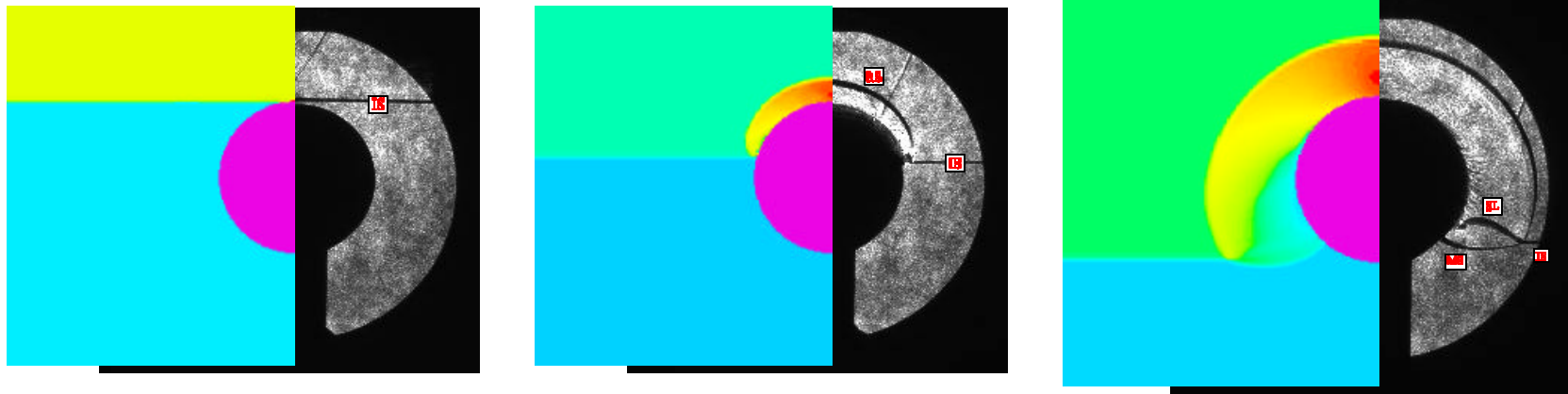
- $Re = 3.4 \times 10^4$
- Free surface geometry
15 cm from nozzle exit
(center of HYLIFE-II
pocket)

**Max. instantaneous
surface ripple ~2 mm
at jet corners**

**Large variations over
tens of msec**



Gross Features of RAGE Simulations of Flow Around Cylinder Agree with Experiment

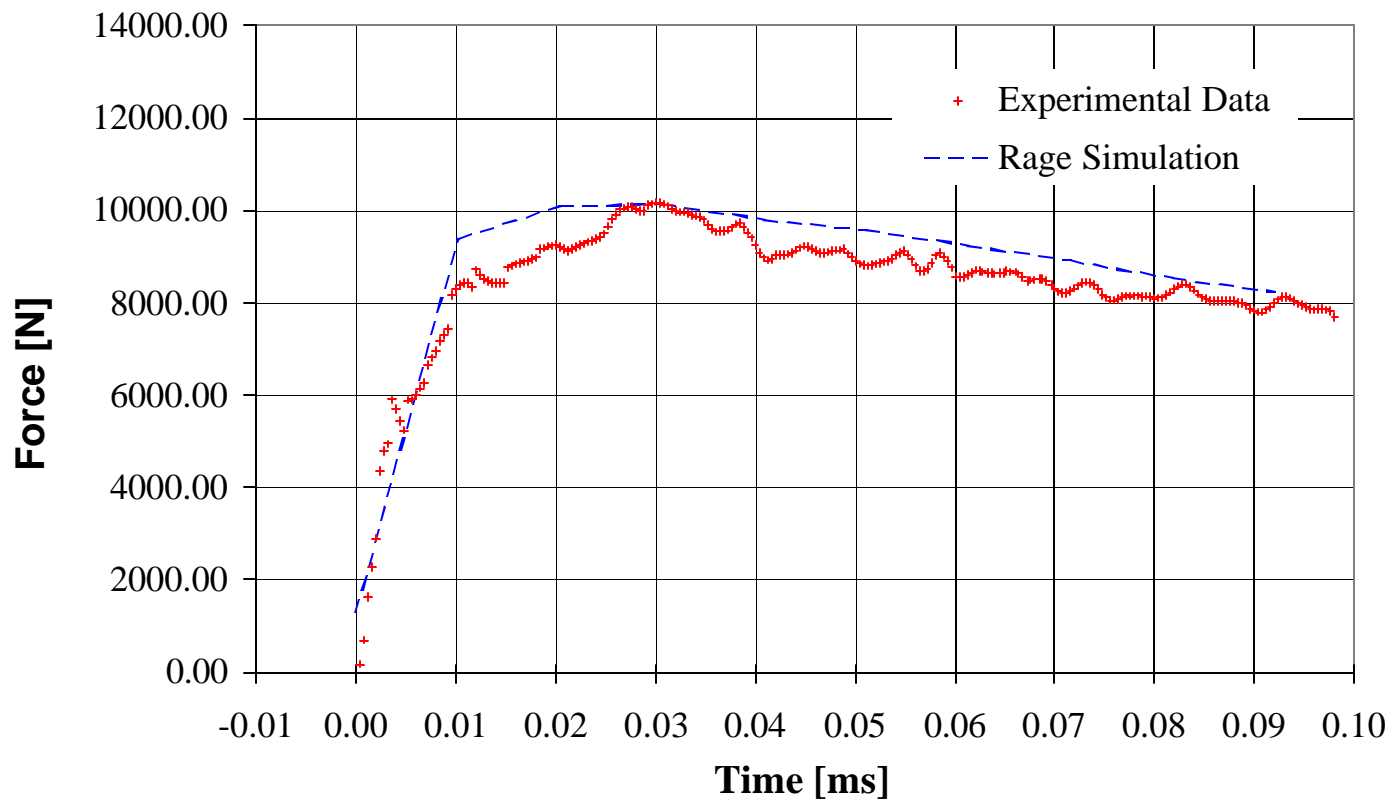


Density contour plots from the numerical simulation using RAGE compared to the experimental shadowgraphs. The times of the numerical simulations are $t=0$, $t=0.03$ and $t=0.08$ ms after a 1.85 Mach shock makes contact with the cylinder. The experimental images were taken at a time of $t=0$, $t=0.05$ and $t=0.09$ ms respectively.



RAGE Simulations of R-M Unstable Interface Experiments

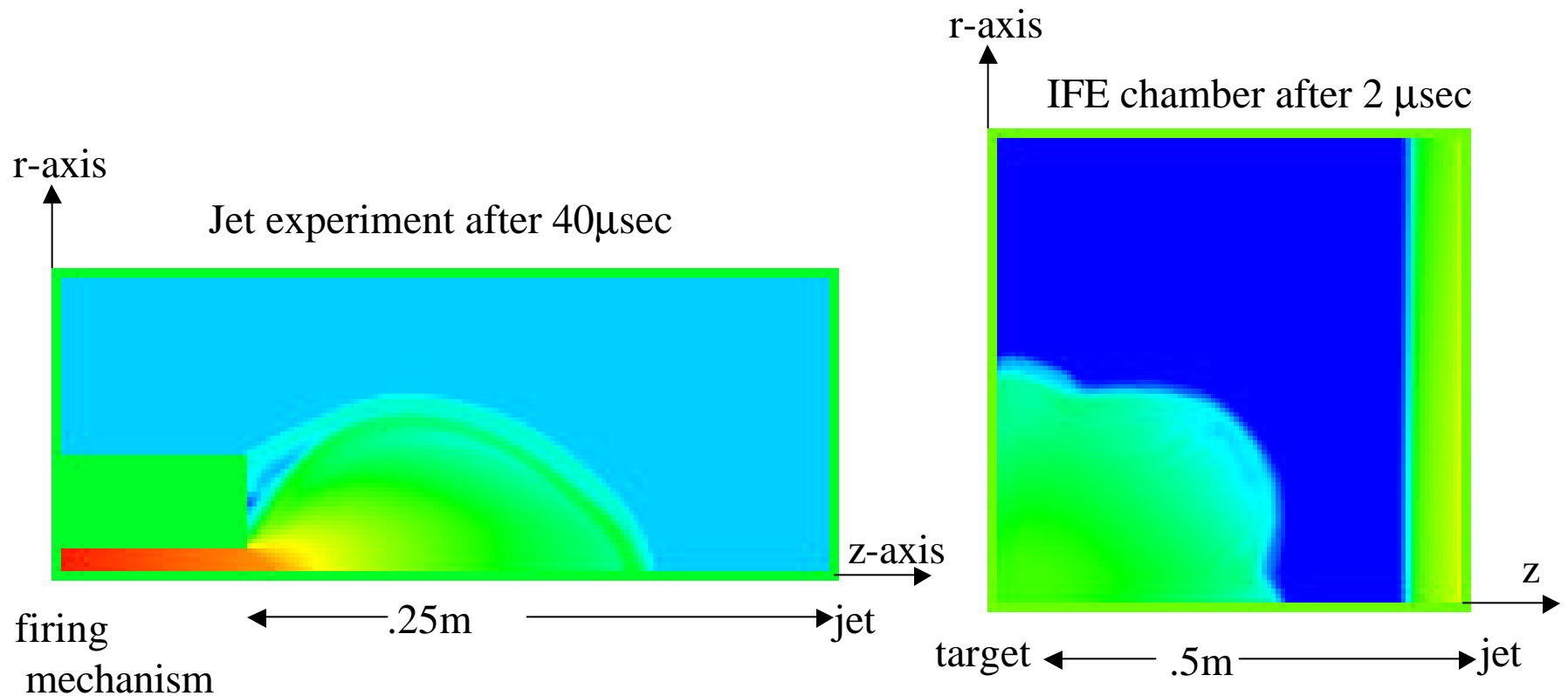
Force on the Cylinder as a Function of Time



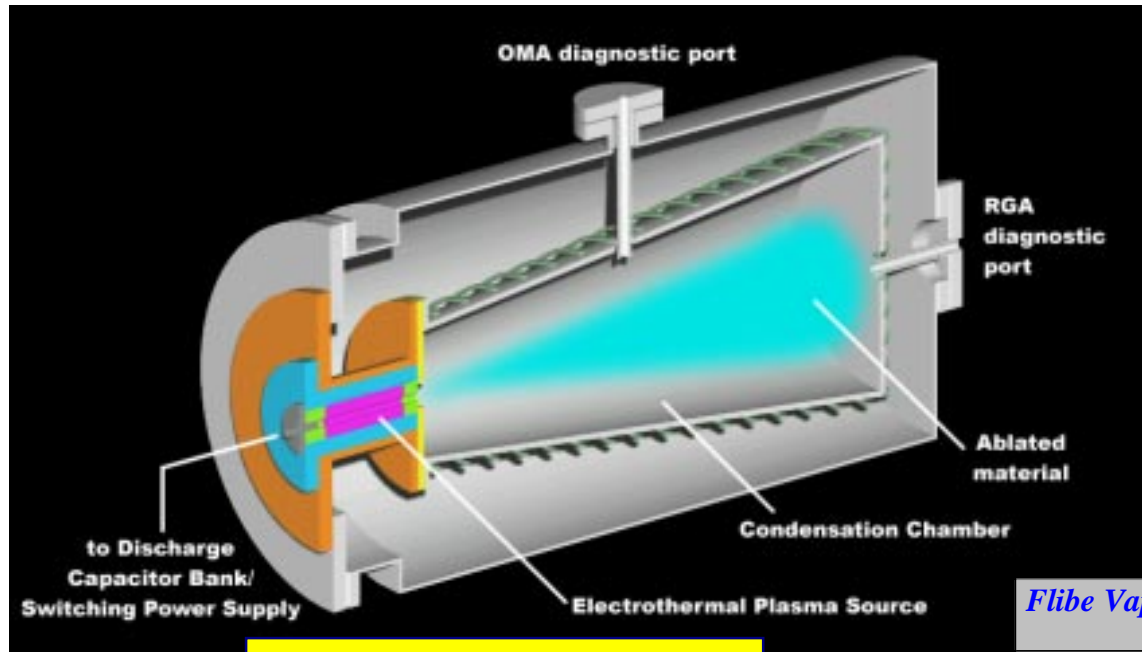
Density Contours of Jet Experiment and IFE Chamber

Profiles demonstrate jetting of ignition products from firing mechanism and more uniform expansion of target

Ablated jet material causes instantaneous density/pressure rise in IFE chamber



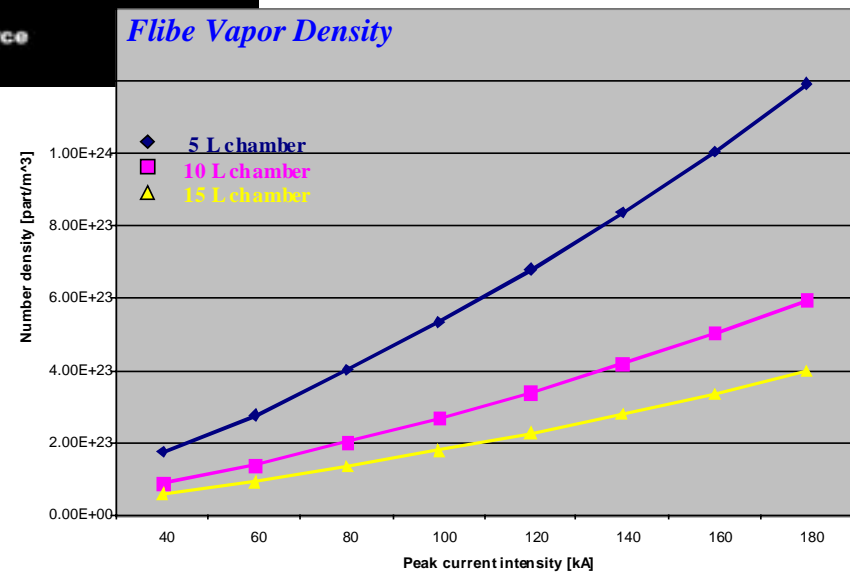
Vapor Clearing Rates for IFE Liquid Chambers



Tube-shaped Flibe plasma source

- ◆ *Partially Ionized, high density low temperature ($\sim 4eV$) Flibe Plasma can be formed by the **Ablation** of a Flibe Liner with a large current discharge*

Expected number of density in the expansion chamber for different chamber sizes

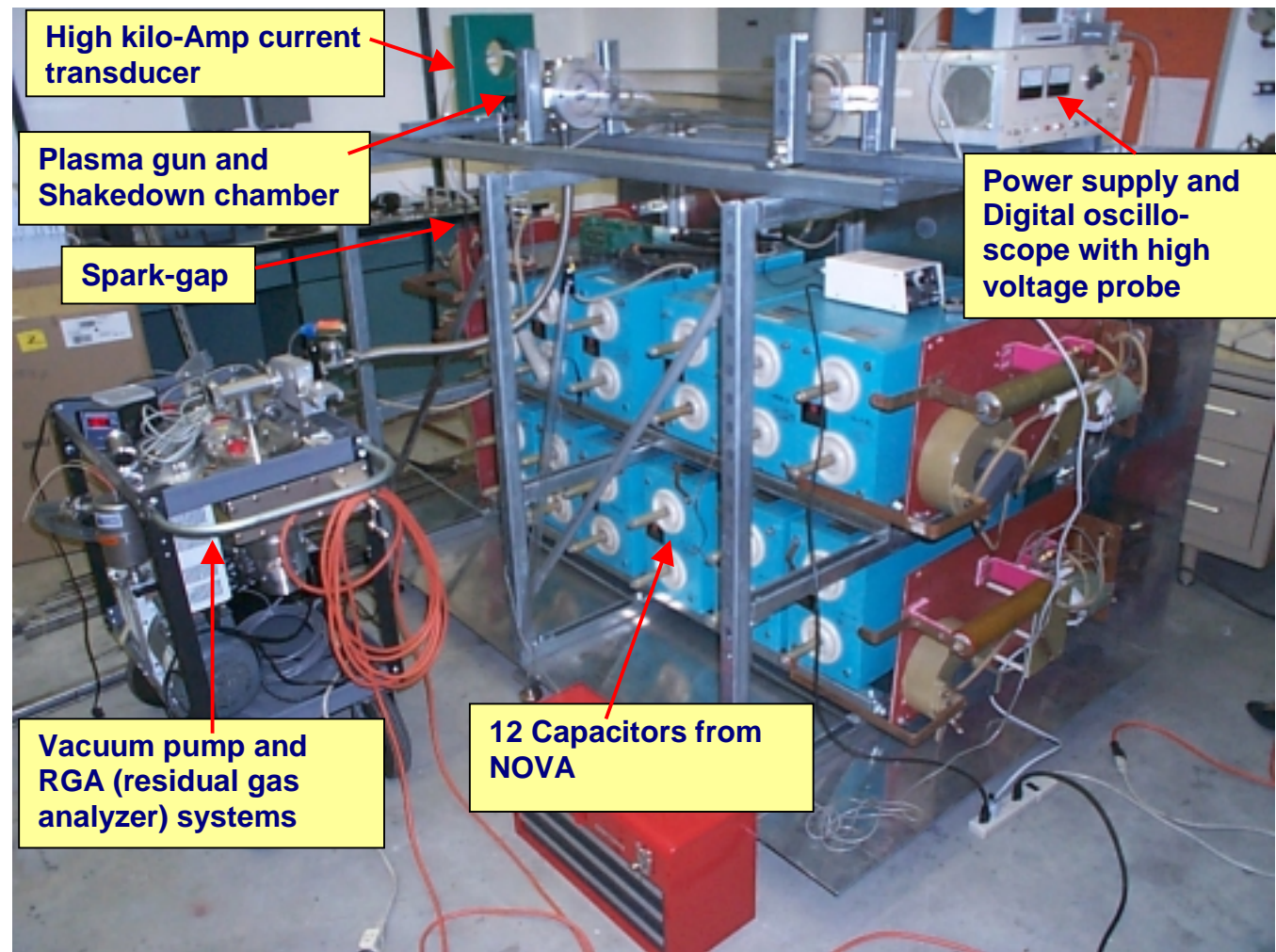


- ◆ *A **HYLIFE** prototypical Flibe vapor density of 10^{18} /cc can be formed in a chamber size of about **5 liters** using a discharge current of **160 kA***

Feasibility Exploration of Vapor Clearing Rates for IFE Liquid Chambers

Principal FY1999/2000 Achievements:

- ◆ Constructed a pulsed electro-thermal plasma launcher (a pulsed energy source that simulates IFE pellet explosion for rapid Flibe vapor generation) using 12 capacitors received from NOVA laser at LLNL.
- ◆ Shakedown tests at 5 kV and 50 μF (one capacitor) have ablated some amount of Lexan (to be quantified). Total maximum energy capacity = 120 kJ.
- ◆ Flibe casting into a cylinder tube (as for ablation) is under evaluation.

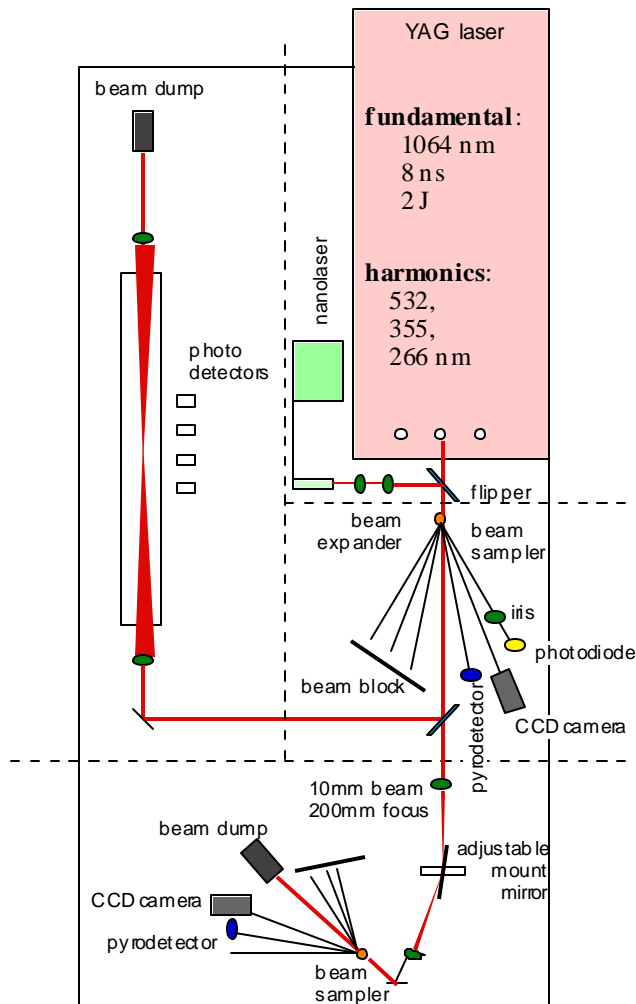


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Laser-Material Interaction Experimental Plan



Final Optics Damage and Protection:

- Damage limits on GIMMs
- Impurity effects on final optics
- Beam quality from liquid mirrors
- Advanced protection concepts

Beam Propagation Physics:

- Beam degradation near/ beyond breakdown
- Effect of background medium

Principal Diagnostics Under Development:

- Beam profile
- Shack-Hartmann wavefront sensor
- Pyroelectric detector
- Fast photodiodes
- Post-test microscopy



Fundamental:

2 J, 8 ns

1.06 μm

Harmonics:

0.532 μm

0.355 μm

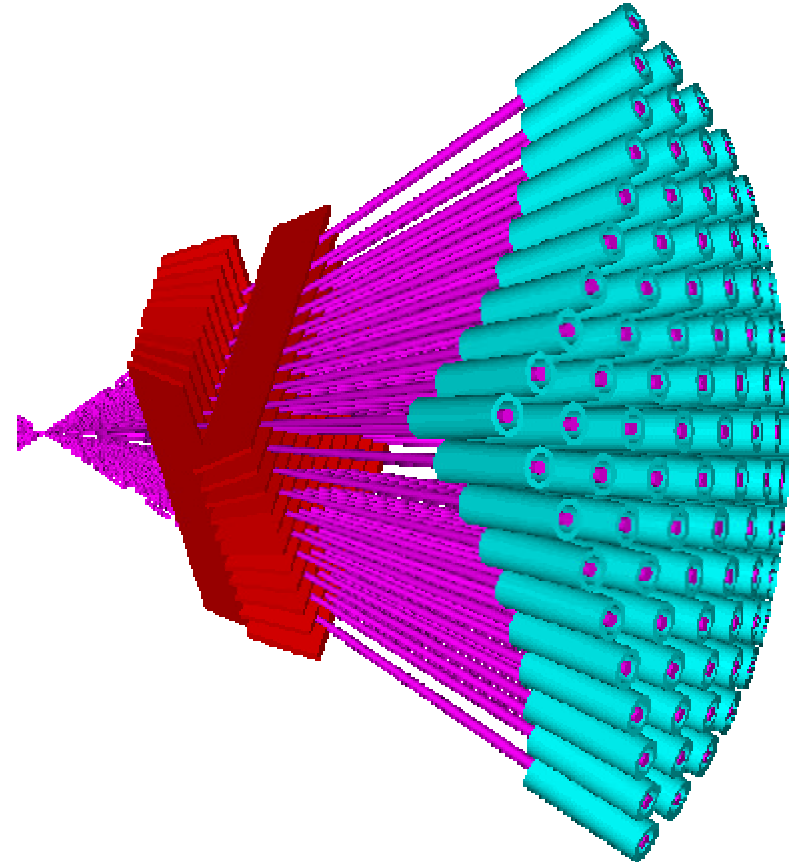
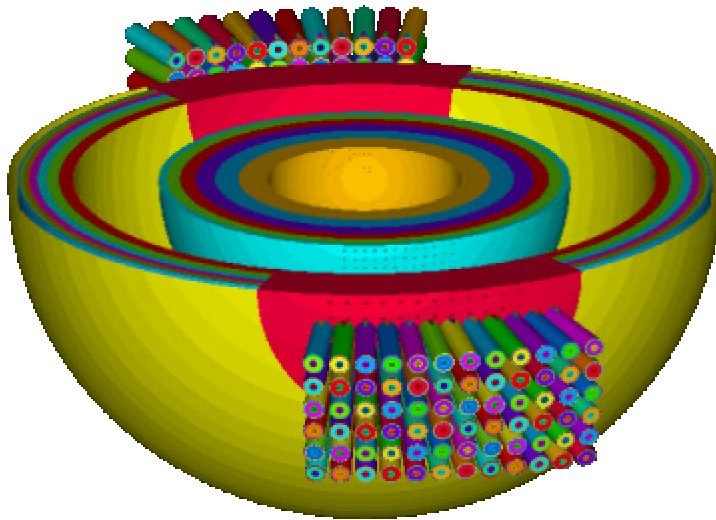
0.266 μm

YAG laser inside cleanroom enclosure (power supply at left)

We are working towards a self-consistent design for the driver/chamber interface



- Realistic, 3-D models are being used to analyze the driver/chamber interface:
 - To study S&E issues related to final focus design



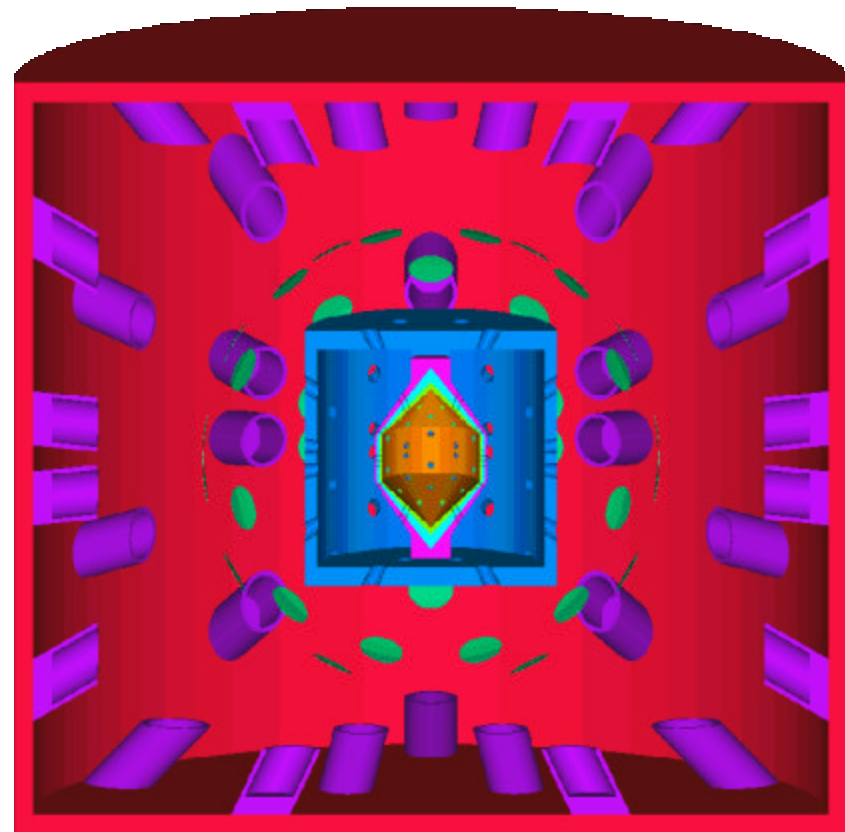
- To determine the importance of precision Flibe jets

Radiation damage issues for Laser-IFE designs are being addressed



- Detailed 3-D models are being developed for S&E and radiation damage analyses
- By using neutron dumps (violet), the fast neutron flux in the focusing optics (located outside of dumps) is reduced by $\sim 4\times$
- Previous 1-D work significantly underestimated the neutron fluence at the focusing optic due to a significant contribution from scattering in the final optic

Model of a DPSSL-modified SOMBRERO target building includes final optics and neutron dumps

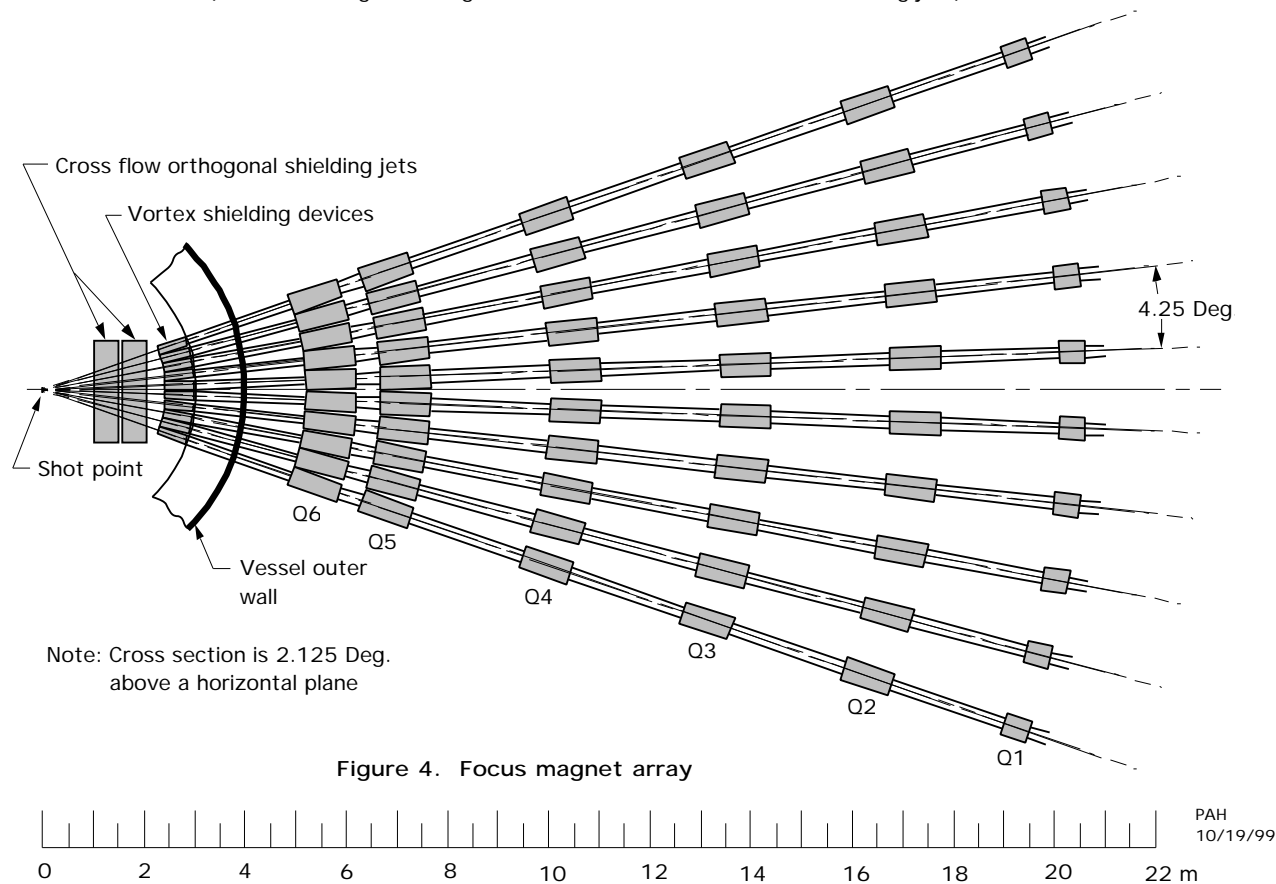


Driver/chamber interface design was updated for HYLIFE-II



Heavy Ion Beam Lines With Magnets (cross section through the shot point)

(This is the magnet configuration for horizontal and vertical shielding jets)



Outline

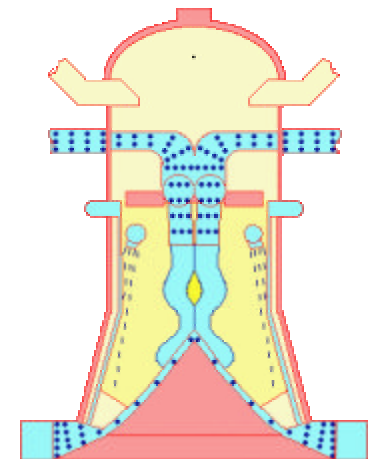


- R&D Planning
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We have completed a loss of coolant/breach of confinement analysis for HYLIFE-II

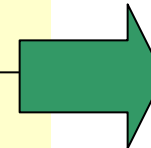


- Upgraded state-of-the-art codes and methodologies have been used to perform an accident analysis for HYLIFE-II IFE power plant design
- Modeled a complete loss-of-coolant accident, with simultaneous break of all beam tubes and failure of the containment building wall
- Thermal-hydraulics, heat transfer, aerosol physics, and fusion product release and transport calculations have been made
- According to the Fusion Safety Standards, a site boundary (1 km) accident dose of 10 mSv (1 rem) triggers the requirement for an evacuation plan



HYLIFE-II

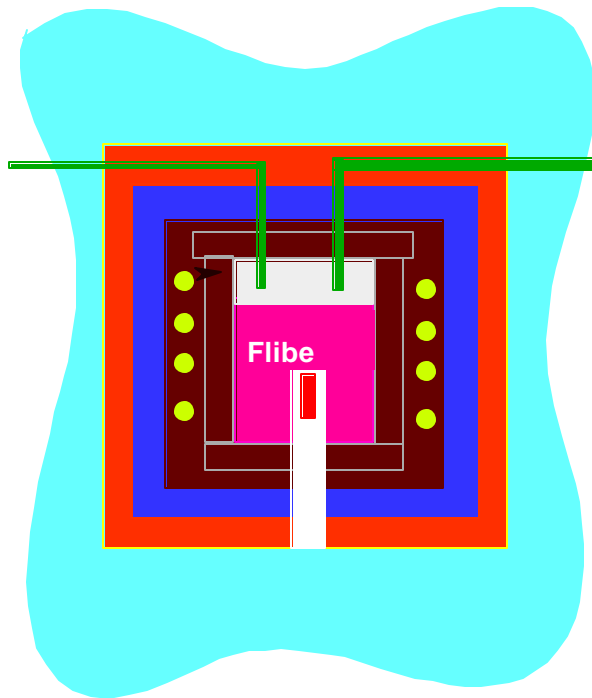
Radioactive source	Mobilized mass/activity	Release fraction	Dose at site boundary
SS304 corrosion/oxidation products	0.5 kg / 1.31×10^{12} Bq	11%	43 mSv / 4.3 mrem
Vaporized Flibe	10 kg / 7.06×10^{15} Bq	12%	564 mSv / 56.4 mrem
HTO trapped in steel structures	1 kg / 4.99×10^{16} Bq	50%	5.34 mSv / 534 mrem



Site boundary dose
of 6 mSv (0.6 rem)
implies that an
evacuation plan
would **not** be needed

Fusion Safety Program Support of IFE Technology

FLIQUIRE



Objectives

- Neutron irradiation by Cf-252 source
- Be and T compound and aerosols mobilized during air or steam ingress
- Tritium permeation through metal surface
- In FY-00, engineering design.
Construction and operation in FY-01

Safety Model Development

- Incorporate Flibe properties into safety codes (ATHENA, MELCOR)
- Support IFE/LLNL colleagues in use of fusion safety codes MELCOR and CHEMCON

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- **Target Fabrication and Injection**
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CREDIBLE TARGET FABRICATION AND INJECTION ARE NEEDED FOR IFE

- Design studies show plausible manufacturing and injection processes and reasonable costs
- We must demonstrate:
 - Technical feasibility of approaches
 - Accuracy can meet requirements
 - Survival of targets during injection
 - Reliability of providing ~5 targets/second, 24 hours a day, >300 days/year
 - Low cost of production — including labor, capital, materials and disposal
- We have now begun to address these issues
 - Need to show a credible pathway to IFE exists during Phase I, before investing in the IRE

Design Studies:

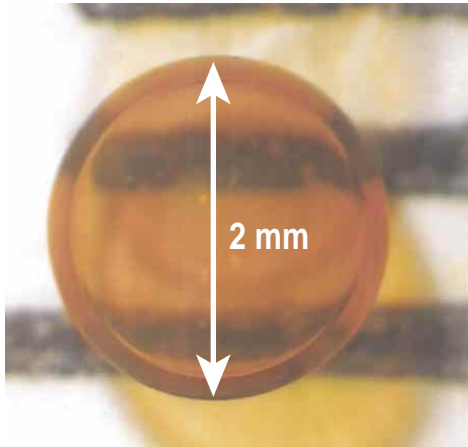
Target factory costs	\$50–90M
Unit cost	20–30¢/target

Typical Specifications

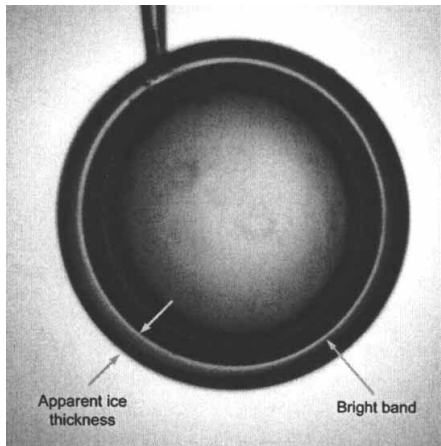
Capsule out-of-round	$\leq 0.1\%$
Ablator thickness	$\leq 1\%$
Outer surface smoothness	$\leq 200 \text{ \AA}$
Inner surface smoothness	$\leq 1 \text{ }\mu\text{m}$
Capsule centered in hohlraum	$\leq 25 \text{ }\mu\text{m}$
Allowed ΔT after layering	$\leq 0.5 \text{ K}$
Location at shot time (indirect)	$\pm 200 \text{ }\mu\text{m}$
(direct)	$\pm 20 \text{ }\mu\text{m}$
Reliability	$\geq 99\%$



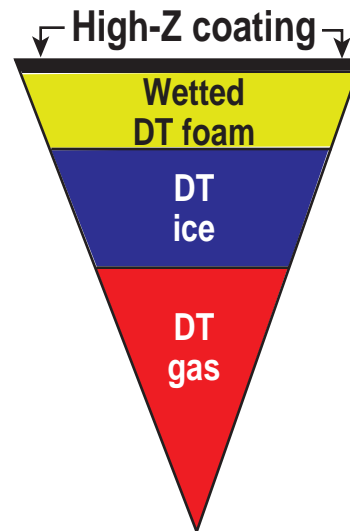
IFE CAN BUILD UPON ICF TARGET FABRICATION TECHNIQUES



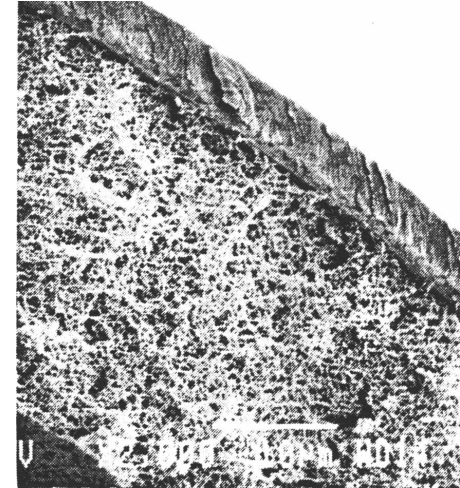
Foam Shells



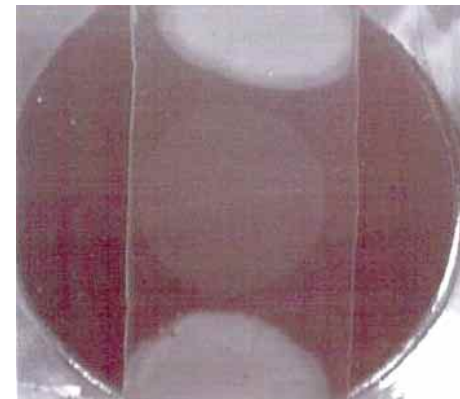
DT Ice Layer



Radiative Preheat
Direct Drive IFE Target Design



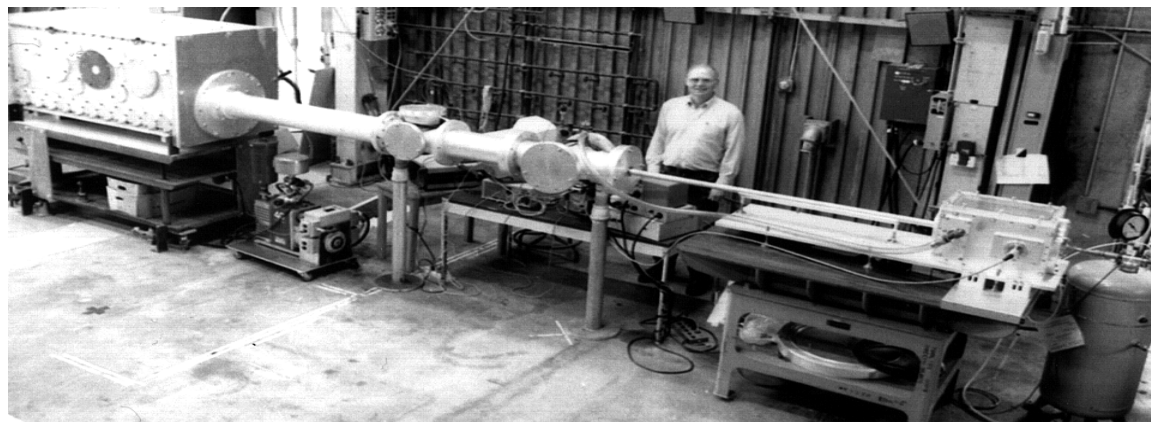
Overcoated Foam



Metal on Foam

PREVIOUS EXPERIMENTS SHOW PROMISING RESULTS FOR TARGET INJECTION

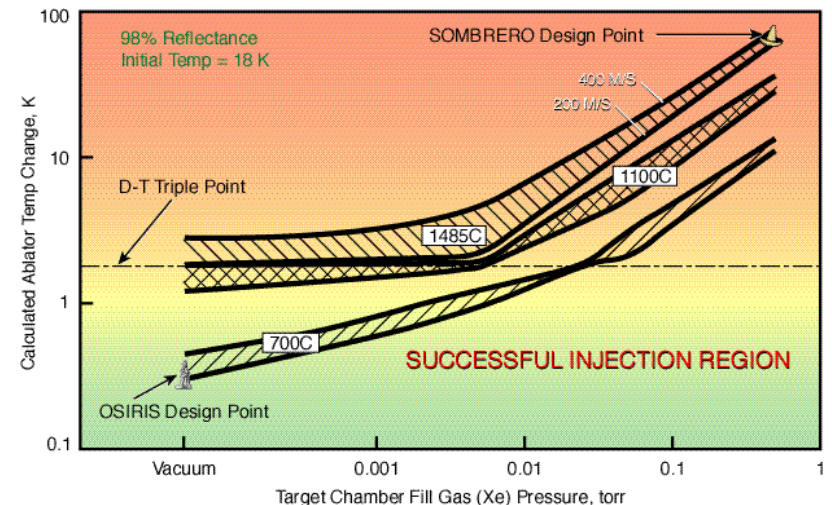
- Gas gun experiments at LBNL have demonstrated the indirect drive requirements can be reliably achieved at room temperature and low rep rate
- Preliminary experiments with surrogate direct drive targets in vacuum at room temperature and $V \approx 100$ m/s also met indirect drive accuracy specs
- Even for high reflectivity targets, direct drive may require development of thermal protection schemes and/or high speed injection and tracking methodologies



IFE Target Injection Experiment at LBNL

DESIGN OF EQUIPMENT FOR DEMONSTRATION OF IFE TARGET INJECTION AND TRACKING IS UNDERWAY

- Prepared Detailed Injection & Tracking Experimental Plan in FY99 (GA-C23241)
 - Document includes both a Technical Plan and a Program Plan (cost and schedules)
- Gas gun is selected as experimental injector
 - capability to meet requirements at lowest cost
 - demonstrated technology with minimum development
 - primary goal is to acquire target data – not develop advanced injection systems
- Continue evaluation of electromagnetic systems for future applications
 - Advantages include non-contacting injection and no propellant gas
 - Depends upon availability of higher current density superconductors
- Design of experimental target injection and tracking system is progressing well
 - Draft system requirements (12/99)
 - Conduct CDR meeting (9/00)
 - Design strategy = highly modular system layout applicable to both direct and indirect drive targets
- Related issues are being addressed
 - Developing scientific basis for successful target injection
 - Target heating during injection subject of recent master's thesis
 - Target fabrication interfaces
 - Coordination of target-related activities (workshops)



Outline



- **R&D Planning**
- **Chamber Technologies**
- **Chamber/Driver Interface**
- **Safety and Environmental**
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Summary



- **IFE technology R&D plans have been drafted and will continue to evolve**
- **Current R&D activities in chamber and target technologies focus on addressing key feasibility issues**
- **Work includes both small scale experiments and modeling by national labs, universities and industry**
- **Current R&D will prepare for decision to proceed with Integrated Research Experiment(s)**